Saidahmed *et al.*
Journal of Electrical Systems and Inf Technol (2024) 11:3
https://doi.org/10.1186/s43067-023-00116-y

Journal of Electrical Systems and Information Technology

RESEARCH **Open Access**

Optimizing juice extraction in sugar mills: application of time delay compensation with intelligent controllers

Mohamed T. F. Saidahmed[1], Ahmed M. Attiya Ibrahim[1*] and Basma Gh. Elkilany[1]

*Correspondence: ahmedattiya@f-eng.tanta.edu.eg

[1] Faculty of Engineering, Tanta University, Tanta, Egypt

Abstract

The juice extraction process plays a crucial role in the sugar production industry, but it often faces challenges due to time delays that can negatively impact efficiency and quality. This paper introduces a Time Delay Compensation (TDC) technique aimed at mitigating this issue. The TDC technique is specifically designed to minimize the adverse effects of time delays, thereby improving control performance. The primary objective of this research is to enhance the efficiency and quality of the juice extraction process, ultimately leading to increased productivity and profitability for sugar mills. To achieve this goal, we conducted an extensive review of existing solutions, highlighting their limitations and associated challenges. In response, we propose a unique and practical solution that can be implemented using MATLAB Processes. Through simulation results, we demonstrate the effectiveness of the TDC technique in suppressing time delay and enhancing control performance, resulting in a significant improvement in extraction efficiency. This work contributes to the field of sugar production by introducing a specialized TDC technique tailored for the juice extraction process in sugar mills.

Keywords: Time-delay control (TDC), Exact and unique state-space model, Delay compensation, Smith predictor

Introduction

In recent years, there has been a growing interest in the field of time-delay systems (TDS), which are commonly referred to as dead times. These TDS are prevalent in various real-world applications of feedback control systems, such as genetic systems, transport delays, and time delays. Time-delay control systems also occur naturally in many real-time applications, including biology, economics, physiology, actuators, sensors, mass transportation, energy transfer, and data transmission over physical networks. However, the presence of dead time in these systems makes controller design challenging and complex. As a result, researchers have been exploring new methods to handle these systems. The approach proposed in this paper focuses on converting state-space systems with delayed control actions to finite-dimensional state-space systems with no delays in the states or control.

The proposed time-delay compensator is a novel compensation technique that has significant contributions in improving the control performance of the juice extraction process in a sugar mill. Compared with other compensating techniques, such as proportional–integral–derivative (PID) controller and Smith predictor [8], the proposed approach provides more accurate and efficient compensation for the time-delay effect in the process. The simulation results show that the proposed compensated technique outperforms other compensating techniques in terms of settling time, overshoot, and steady-state error. The proposed approach provides a practical solution for improving the control performance and efficiency of the juice extraction process in sugar mills. It can also be applied to other industrial processes that suffer from time-delay effect.

The paper is structured as follows: Section II provides background information on the history of time-delay compensation techniques. Section III presents related previous compensating methods that address the removal of the delay factor in the juice extraction process in a sugar mill. In Section IV, a novel and accurate model of a delayed control system with no delay in either the state or control action is derived. Finally, Section V concludes the compensatory approach introduced with some closing remarks.

Background and related work

Recently, the compensatory method introduced in [1] has recently proven to be an effective approach for removing the delay component from closed-loop delay systems, confining it solely to the control action, and improving system performance. This method eliminates time delay from the closed-loop system and may lead to system stabilization using well-known controller design in the time domain. However, it cannot be used with unstable poles or in the presence of disturbances. Other approaches, such as state variable techniques, have been heavily used in the literature, but new approaches introduced by Saidahmed in [1, 5] use finite-dimensional closed-form solutions to remove delay factors from system variables and augment only their parameters. These new models are considered general delay systems that contain all delayed systems as special cases when their delay factors vanish. This work is inspired by Saidahmed's [1, 5] approach, which completely converts infinite-dimensional delay systems into finite-dimensional ones without compensation, adaptation, or approximation, retaining all original characteristics without any changes. These models allow all control theorems established for state-space linear time-invariant systems to be easily applied without modifications or approximation. This paper focuses on the Saidahmed problem in the context of linear systems with an input lag and compares the results obtained with those introduced in [1].

Problem description and previous compensated approach for TDS

This section focuses on utilizing the compensatory technique presented in [1, 3, 5] to eliminate the delay component from a closed-loop delayed system, restricting it only to the control action. As previously mentioned, the presence of a delay factor in a process control system when analyzing performance is complex to be handled conventionally. To address this issue, some methodologies have attempted to integrate structural elements that simulate process dynamics into operation. One such approach employs a compensator control method detailed in [1, 3–5], which serves as an excellent example of this technique. This method involves utilizing a mathematical model of the process to incorporate a delay component only in its control action.

As described in [2], the juice extraction process is a crucial subprocess in a sugar mill, and it is the first step in the process. As illustrated in Fig. 1, the bagasse (cane fiber) is transported to the Donnelly chute (buffer) by a cane carrier that is operated by a motor [2, 6, 7, 9]. It is essential to maintain the cane level in the buffer at a specific predetermined value to extract the maximum amount of juice. If the cane level falls below the set point, the cane carrier motor is sped up, and if it rises above the set point, its speed is decreased. The cane fibers are crushed by a set of rollers, resulting in the extraction of the primary juice. The waste bagasse can be used as a fuel for steam generation to run turbines for electricity production. The control system is responsible for maintaining two critical parameters: the cane level (L) and the torque of the rollers (T). The flap position (F) and the angular velocity (V) of the rollers are the manipulated input variables controlled by the system.

The waste bagasse can be utilized as a source of fuel for generating electricity using steam-powered turbines. The control system must maintain two critical parameters, namely the cane level (L) and the torque of the rollers (T). The input variables that the control system modifies are the flap position (F) and the angular velocity (V) of the rollers.

To determine two separate transfer functions for the subprocess, which involves four variables (L, T, F, and V), the MATLAB system identification tool is utilized. The first transfer function, G1, has input F and output T, while the second transfer function, G2, has input V and output L. (1) and (2) depict the resulting models. It is evident that the first plant has a dead time of 4 s, whereas the second plant does not have any dead time.

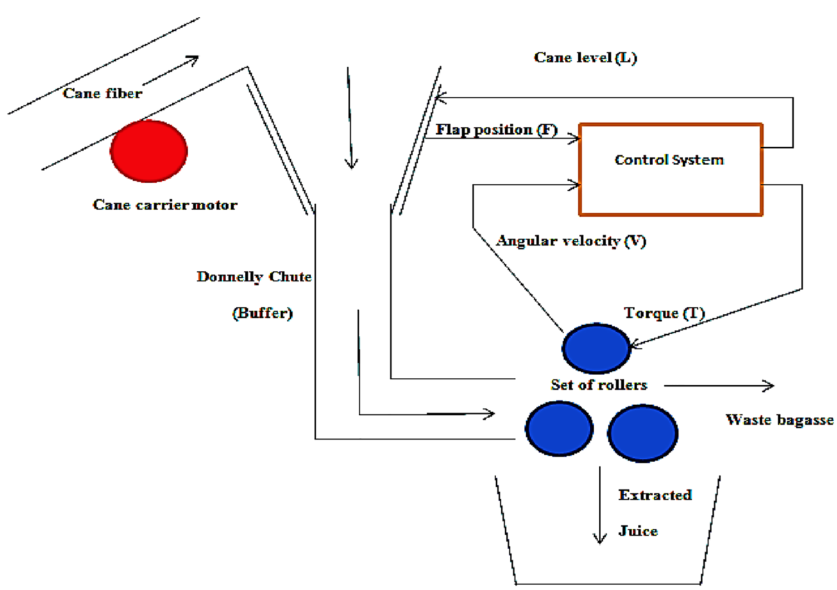

Fig. 1 Juice extraction process [2]

$$G1(s) = \frac{T(s)}{F(s)} = \frac{-7.2e^{-4s}}{(1 + 414s)} \tag{1}$$

$$G2(s) = \frac{L(s)}{V(s)} = \frac{-400000}{\left(1 + 3.75 * 10^8 s\right)} \tag{2}$$

The MIMO model of a process presents a significant challenge in designing a controller that can effectively control all the manipulated and control variables due to their strong cross-coupling as shown in the schematic representation in Fig. 2. To overcome this challenge, it is recommended to decouple the MIMO model into SISO models, which will simplify the controller design process as shown in Fig. 2. To achieve this, a decoupled SISO mathematical model, which has been previously documented in literature, can be used for control system analysis and design. The model, [2] as shown in (1), considers flap position as the input and mill torque as the output.

A schematic representation of a crushing machine is shown in Fig. 1. Recent research [2] suggests that the flap mechanism's placement and turbine speed be used to regulate the chute height of the buffer and the torque of the mill in order to ensure optimal juice extraction.

The desired closed-loop system with compensation is represented by the following equation:

$$Gp(s) = \frac{Y(s)}{U(s)} = \frac{T(s)}{F(s)} = \frac{-7.2}{414S + 1} \tag{3}$$

demonstrates the model's accuracy, [2] as demonstrated in (1, 3), which uses flap position as the input and mill torque as the output and may be applied to the design and analysis of control systems.

Previous compensated approach for sugar mill [2]

Using the Smith predictor [2, 6, 7, 9], a control system used to compensate for dead time in a sugar mill system as applied in [2]. Dead time is the delay between when an input is applied and when the output of the system responds. The Smith predictor uses a combination of two controllers, one for the process and one for the dead time, to reduce the effects of dead time on the system. The process controller adjusts the output of the system based on current conditions, while the dead-time controller

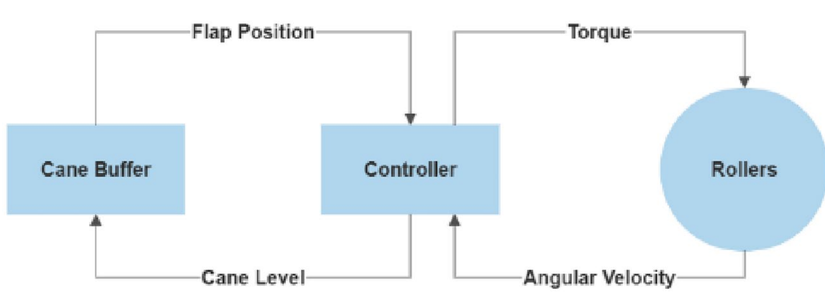

Fig. 2 Schematic of control system for juice extraction process

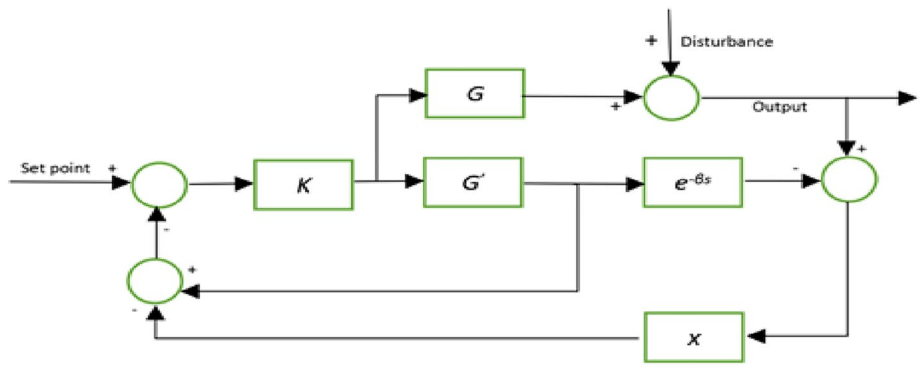

Fig. 3 Smith predictor architecture [2]

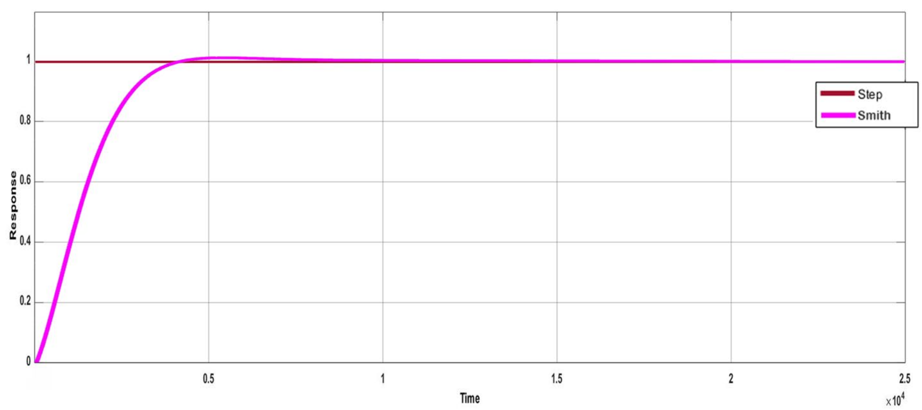

Fig. 4 Set-point tracking response of Smith predictor [2]

predicts future conditions and adjusts accordingly as shown in Fig. 3. This allows for faster response times and better performance from the sugar mill system. The Smith predictor can also be used to reduce overshooting and improve stability in systems with long dead times.

By using this control system [2], sugar mills can increase efficiency and reduce costs associated with long dead times as shown in Fig. 4.

Proposed time-delay compensator for sugar mill system

In this section, we present a novel and distinctive approach for compensating time-delay elements in the juice extraction process using a sugar mill, as previously introduced in [2]. Our proposed method involves the application of Saidahmed's theorems [1, 3–5] to the sugar mill system depicted in Fig. 5. By employing these theorems, we derive a unique and precise alternative model (1) for our system. Subsequently, we employ various controllers with the newly compensated sugar mill system to enhance its performance.

To begin, we utilize Saidahmed's theorems [1, 5] to establish a methodology for transforming a unity feedback delayed control system, as illustrated in Fig. 6, into an exact state-space representation that eliminates delays in state variables and control action.

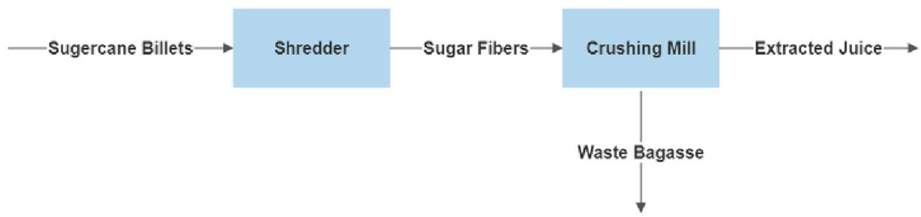

Fig. 5 Delayed control system [5]

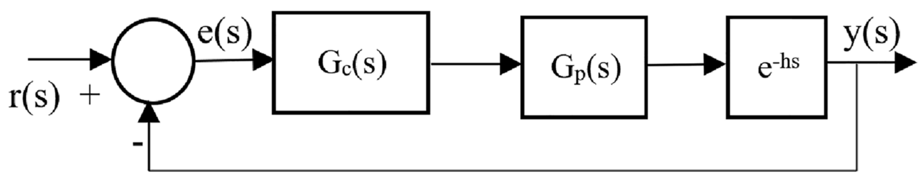

Fig. 6 Various stages of juice extraction process

Here,

$$Gp(s) = G1(s) * G2(s) = \frac{-7.2}{(1 + 414s)} * \frac{-400000}{\left(1 + 3.75 * 10^8 s\right)} = \frac{2880000}{\left(1 + 375000414s + 1.5525 * 10^{11} s^2\right)} \tag{4}$$

and

$$G_c(s) = k_p + \frac{k_i}{s} + k_d s = \frac{k_p s + k_i + k_d s^2}{s} \tag{5}$$

Thus, total transfer function: Y(s)/R(s)

$$\frac{Y(s)}{R(s)} = \frac{k_p s + k_i + k_d s^2}{s} * \frac{2880000}{\left(1 + 375000414s + 1.5525 * 10^{11} s^2\right)} \tag{6}$$

It is well known that the system in Fig. 4 has the transfer function from the input signal to the output of the system which takes the form:

$$\frac{y(s)}{e(s)} = H(s)e^{-hs} \tag{7}$$

where

$$H(s) = G_c(s)G_p(s) = \frac{N(s)}{D(s)} \tag{8}$$

where $G_c(s)$ is a controller T.F. and $G_p(s)$ is the system plant T.F.

It is an easy task to show that (7) can be represented in the form of state space as:

$$\dot{x}(t) = Ax(t) + Be(t - h)\forall t \geq 0 \tag{9}$$

$$y(s) = Cx(s) \tag{10}$$

where A ∈ Rnxn, B ∈ Rnx1, and C ∈ R1xn are constant state matrices.

As proven in Saidahmed [1, 5, 6], the equation of the system in Fig. 4 has a unique and exact alternative state-space representation, described in (11), in the form of singular system.

$$T(h)\dot{x}(t) = A^*(h)x(t) + Br(t) - B^*(h)\dot{r}(t)\forall t \geq h \tag{11}$$

where

$$T(h) = (I - A(h)BC) \tag{12}$$

$$A^*(h) = (A - BC) \tag{13}$$

$$B^*(h) = A(h)B \tag{14}$$

It is well known that some practical delayed control systems, the matrix T(h) is invertible so (11) can be written as:

$$\dot{x}(t) = \tilde{A}(h)x(t) + \tilde{B}(h)r(t) - \hat{B}(h)\dot{r}(t)\forall t \geq h \tag{15}$$

where

$$\tilde{A}(h) = T(h)^{-1}A^*(h) \tag{16}$$

$$\tilde{B}(h) = T(h)^{-1}B \tag{17}$$

$$\hat{B}(h) = T(h)^{-1}B^*(h) \tag{18}$$

Since the MRH of (15) has a derivative in r(t), it is an easy task to use the transformation:

$$\theta(t) = x(t) + \hat{B}(h)r(t) \tag{19}$$

Using (19), we end up with:

$$\dot{\theta}(t) = \tilde{A}(h)\Big(\theta(t) - \hat{B}(h)r(t)\Big) + \tilde{B}(h)r(t) \tag{20}$$

Collecting similar terms, we get:

$$\dot{\theta}(t) = \tilde{A}(h)\theta(t) + \Big(\tilde{B}(h) - A(h)\hat{B}(h)\Big)r(t) \tag{21}$$

Then,

$$\dot{\theta}(t) = \tilde{A}(h)\theta(t) + B^{**}(h)r(t) \tag{22}$$

$$y(t) = Cx(t) = C\theta(t) - D(h)r(t) \tag{23}$$

where

$$B^{**}(h) = \left(\tilde{B}(h) - A(h)\hat{B}(h)\right) \tag{24}$$

$$D(h) = C\hat{B}(h) \tag{25}$$

In case of PID controller as:

$$G_c(s) = k_p + \frac{k_i}{s} + k_d s = \frac{k_p s + k_i + k_d s^2}{s} \tag{26}$$

where k_p is the proportional gain, k_i is the integral gain, and k_d is the derivative gain.

With $G_p(s)$ of the process, it takes the first-order form as:

$$G_p(s) = \frac{k}{as^2 + bs + c} \tag{27}$$

where k, a, b, and c are the process parameters.

$$\frac{y(s)}{e(s)} = \frac{kk_i + kk_p s + kk_d s^2}{as^3 + bs^2 + cs} e^{-hs} \tag{28}$$

$$\zeta(s) = \frac{e(s)}{as^3 + bs^2 + cs} e^{-hs} \tag{29}$$

$$y(s) = \left(kk_i + kk_p s + kk_d s^2\right)\zeta(s) \tag{30}$$

In the time-domain form, (28) can be represented as:

$$a\dddot{\zeta}(t) + b\ddot{\zeta}(t) + c\dot{\zeta}(t) = e(t-h) \tag{31}$$

$$y(t) = kk_i\zeta(t) + kk_p\dot{\zeta}(t) + kk_d\ddot{\zeta}(t) \tag{32}$$

To have (31) in a state-space form, we let

$$\zeta(t) = x_1(t), \dot{\zeta}(t) = \dot{x}_1(t) = x_2(t), \ddot{\zeta}(t) = \dot{x}_2(t) = x_3(t)$$

and $\dddot{\zeta}(t) = \dot{x}_3(t)$

Then,

$$\dot{x}_3(t) = -\frac{b}{a}x_3(t) - \frac{c}{a}x_2(t) + \frac{1}{a}e(t-h) \tag{33}$$

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \\ \dot{x}_3(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & \frac{-c}{a} & \frac{-b}{a} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{1}{a} \end{bmatrix} e(t-h) \tag{34}$$

Then, we get:

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \\ \dot{x}_3(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & \frac{-c}{a} & \frac{-b}{a} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{1}{a} \end{bmatrix} e(t-h) \tag{35}$$

$$y(t) = \begin{bmatrix} kk_i & kk_p & kk_d \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \end{bmatrix} \tag{36}$$

where
$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & \frac{-c}{a} & \frac{-b}{a} \end{bmatrix}$, B = $\begin{bmatrix} 0 \\ 0 \\ \frac{1}{a} \end{bmatrix}$, and C = $\begin{bmatrix} kk_i & kk_p & kk_d \end{bmatrix}$
It is clear that the T(h) of (35) takes the form:

$$T(h) = I - A(h)BC$$

which is invertible for $\forall t \geq h$ and k_p, k_i, and k_d are chosen so that the MRH term in (35) ≠ I.

Under this condition, the unique and exact closed-form solution can be easily obtained based on theorem and given in (15), (22) and (23).

Applying the new approach on sugar mill T.F. in (14) with PID controller

$$Gp(s) = \frac{Y(s)}{R(s)} = \frac{2880000}{\left(1 + 375000414s + 1.5525 * 10^{11}s^2\right)} \tag{38}$$

and delay 4 *sec*, we get that:k = 2880000, a = $1.5525 * 10^{11}$, b = 375000414, and c = 1
and PID controller:

$$G_c(s) = \frac{-0.236s - \frac{0.236}{137} - 23.37822s^2}{s} \tag{39}$$

We get that:

$$k_p = -0.236, k_i = \frac{-0.236}{137}, and k_d = -23.37822$$

We end up with the new approach matrices of the exact and unique state-space form of sugar mill system:

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & -6.4412 * 10^{-12} & -0.0024 \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ 0 \\ 6.4412 * 10^{-12} \end{bmatrix}, and$$
$$C = \begin{bmatrix} -4.9612 * 10^3 & -679680 & -6.7329 * 10^7 \end{bmatrix}$$

$$T(h) = (I - A(h)BC) = \begin{bmatrix} 1 & 0 & 0 \\ 3.1956 * 10^8 & 1 & 4.3368 * 10^{-4} \\ -7.6695 * 10^{-11} & -1.0507 * 10^{-8} & 1 \end{bmatrix}$$

Hence,
T(h) is invertible for $\forall t \geq h$

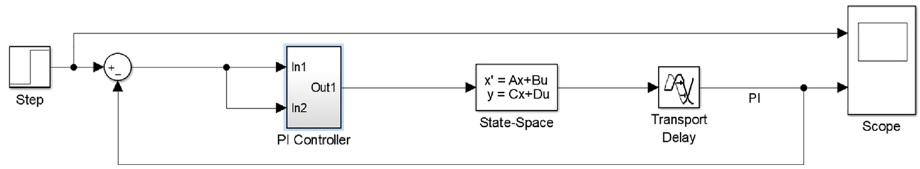

Fig. 7 Sugar mill new compensated approach with PSO-tuned PI controller

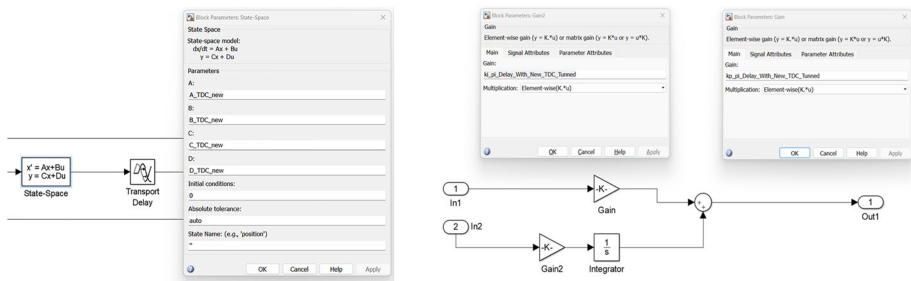

Fig. 8 Parameters of sugar mill new compensated approach with PSO-tuned PI controller

PI controller tuned with PSO

In this next step, we will utilize the PI controller in conjunction with particle swarm optimization (PSO)—an optimization technique based on the behavior of social animals such as fish and birds. Each particle in the PSO algorithm represents a potential solution and traverses the search space using its unique velocity vector. The velocity vector has two components: cognitive, which directs the particle toward its best solution, and social, which directs the particle toward the global best solution discovered by other particles in the swarm. Our goal is to enhance sugar mill system performance by compensating for dead time, as dead time can produce various detrimental effects as implemented in Fig. 7.by using a PI controller then through their velocity vectors, the particles interact with one another and explore different parts of the search space concurrently, enabling them to converge on an optimal solution more rapidly than traditional optimization algorithms such as gradient descent or simulated annealing resulting in a tuned PI parameters.

The objective of tuning a PI controller is to identify parameters that will result in the desired response from the controlled system. To accomplish this, two parameters, proportional gain (Kp) and integral gain (Ki), are optimized using PSO. The appropriate objective function for this optimization problem should be selected based on the desired response from the system as in Fig. 8 that shows parameters configuration of PSO-tuned PI controller; for instance, if minimal overshoot is desired, an objective function that penalizes large overshoots during simulation runs should be used. After selecting the objective function, PSO can be utilized to determine the values of Kp and Ki that minimize this function while still fulfilling any constraints imposed on these parameters (e.g., the maximum allowable overshoot).

Implementing the new compensated approach with PSO-tuned PI controller in the sugar mill system yields a response characterized by enhanced speed and optimized performance comparing to the smith predictor response as in Fig. 9.

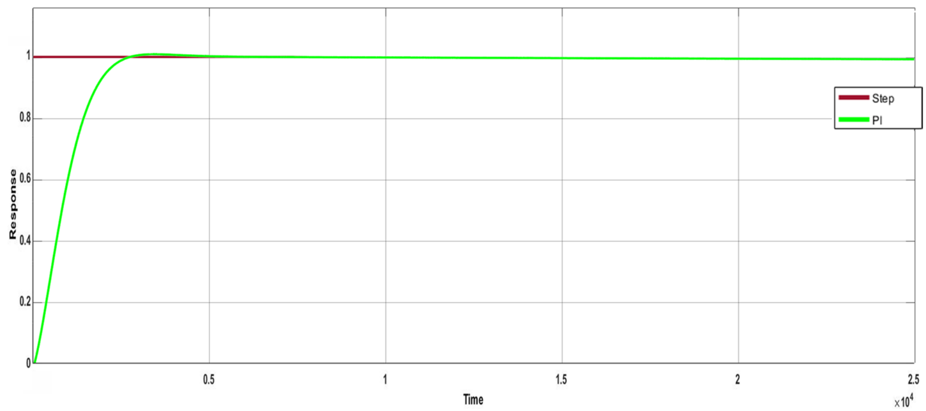

Fig. 9 Set-point tracking response of new compensated approach with PSO-tuned PI controller

PID controller tuned with fuzzy logic

We will now employ the PID (proportional–integral–derivative) controller [9], which is a feedback control system that adjusts its output in response to alterations in an input signal using three distinct terms: proportional, integral, and derivative. The proportional term modifies the output based on the difference between its present and target values, the integral term modifies it based on the duration it has been away from the target, and the derivative term modifies it based on the rate of change. By adjusting these three terms, a PID controller can be optimized to achieve the desired performance using a fuzzy logic system as implemented in Figs. 10 and 11.

To implement the fuzzy logic-tuned PID controller in a sugar mill system, we analyze the dynamics of the mill process and determine the appropriate PID controller structure.

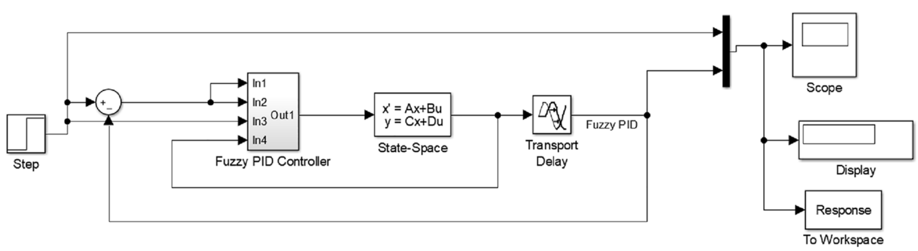

Fig. 10 Sugar mill new compensated approach with fuzzy logic-tuned PID controller

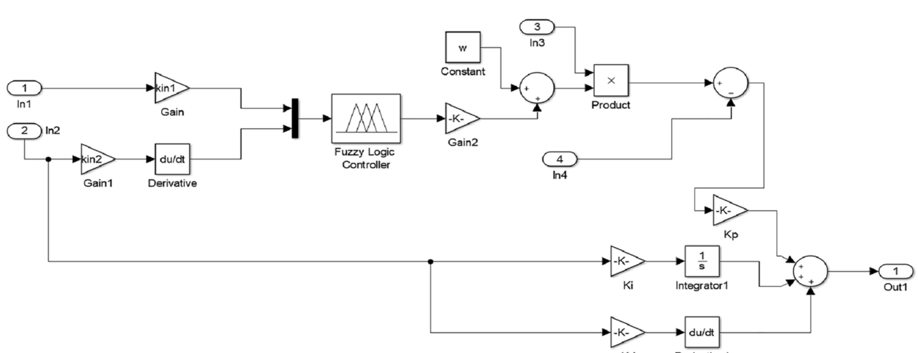

Fig. 11 Fuzzy logic-tuned PID controller

Fig. 12 Fuzzy logic-tuned PID inference system memberships and rules

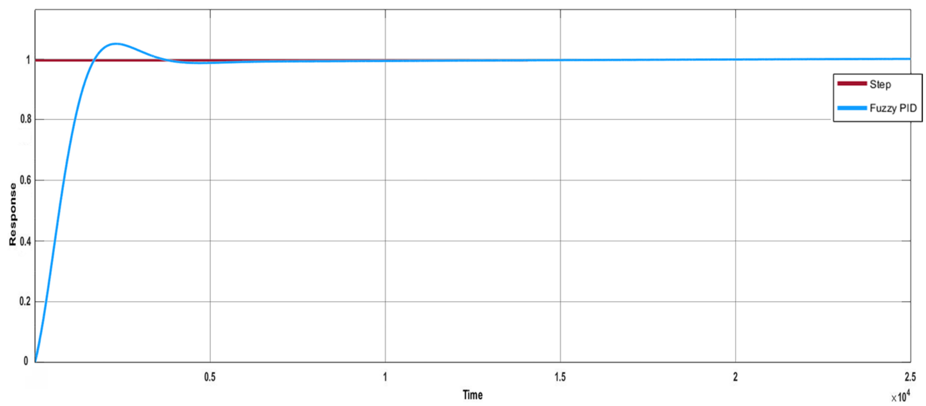

Fig. 13 Set-point tracking response of new compensated approach with fuzzy logic-tuned PID controller

We design a fuzzy logic system that incorporates linguistic variables, fuzzy sets, membership functions, and fuzzy rules based on expert knowledge and experience as in Fig. 11.

Using a rule-based inference mechanism, we evaluate the control actions based on the current inputs and outputs of the sugar mill system as in Fig. 12. This mechanism involves fuzzifying the inputs, applying fuzzy rules, and aggregating the results to obtain a fuzzy output. The fuzzy output is then converted into a crisp control signal. The tuning of the PID controller's parameters is performed using the fuzzy logic system. We define fuzzy sets and membership functions for each parameter, such as the proportional gain, integral gain, and derivative gain. The fuzzy logic system utilizes the current error, error change rate, and integral of the error as inputs to dynamically adjust these parameters.

By incorporating fuzzy logic into the PID controller, we can effectively handle the complexities and nonlinearity of the sugar mill system. The adaptive tuning of the controller's parameters improves the system's response time, stability, and tracking accuracy, even in the presence of uncertainties and disturbances as in Fig. 13.

Once these factors have been determined, they can be modified manually or automatically. Manual techniques require manually tweaking each parameter until desired performance is obtained; automated methods entail automatically modifying them using software algorithms such as genetic algorithms or particle swarm optimization algorithms until desired performance is achieved. Both approaches have advantages and downsides; manual methods take longer but provide more flexibility, while automated methods take less time but may not always identify optimal answers due to their dependence on heuristics rather than exact calculations.

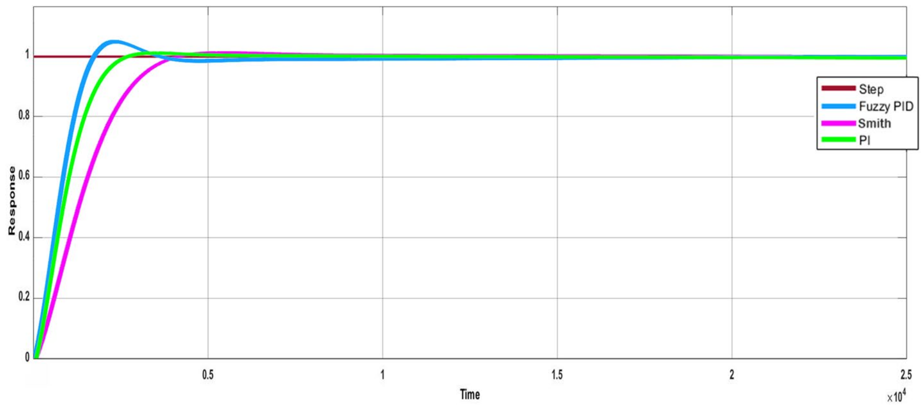

Fig. 14 Set-point tracking response of (a) fuzzy PID, (b) Smith predictor, and (c) PI with PSO

Finally, the performance of a sugar mill system using PI controller tuned with PSO, PID controller tuned with fuzzy logic, and Smith predictor was compared. The results showed that the PI controller tuned with PSO had the best performance in terms of settling time, overshoot, and rise time compared to other implemented compensators as in Fig. 14. The PID controller tuned with fuzzy logic had a slightly longer settling time but a lower overshoot and rise time than the PI controller. Finally, the Smith predictor had the longest settling time but the lowest overshoot and rise time.

Conclusion

In conclusion, Fig. 14 shows that the PI controller tuned with PSO had the best overall performance for this sugar mill system. It had the shortest settling time, lowest overshoot, and fastest rise time. The PID controller tuned with fuzzy logic also performed well but was slightly slower in terms of settling time. Finally, the Smith predictor had the longest settling time.

Acknowledgements
Not applicable.

Author contributions
AMAI conceived and designed the research study, conducted the experiments, analyzed the data, and wrote the research manuscript. BGE provided guidance and supervision throughout the research process. MTFS supported the research with information and theory, contributed to the interpretation of results, and provided critical revisions to the manuscript.

Funding
The research received no financial funding; however, the authors gratefully acknowledge the invaluable assistance, guidance, and support provided by Prof. Mohamed and Dr. Basma. Their contributions in terms of sharing information, offering technical expertise, and providing meticulous revisions greatly enhanced the quality of this study.

Availability of data and materials
Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

Competing interests
The authors declare that they have no competing interests.

Received: 2 August 2023 Accepted: 10 October 2023
Published online: 04 January 2024

References

1. Faheem Saidahmed MT, Saidahmed MEI (2018) A new approach for treating a time delay system: a state space approach. In: 2018 14th international computer engineering conference (ICENCO). IEEE, Cairo, pp 119–124
2. Sunori SK, Joshi O, Jethi GS, Singh B, Juneja PK (2020) Mathematical model determination and control of juice extraction process of sugar mill. In: 2020 IEEE 5th international conference on computing communication and automation (ICCCA), Greater Noida, India, pp 106-108. https://doi.org/10.1109/ICCCA49541.2020.9250793
3. Saidahmed MT (1992) A novel approach for designing a feedback controller for a wind tunnel model involving a delay. In: Proceedings of the 35th Midwest symposium on the circuits and systems, 9–12 August 1992
4. Saidahmed MTF (1991) Design of a smistate estimator for a class of time delay generalized state space systems. In: Proceedings of the twenty- second annual, Pittsburgh, 2–3 May 1991
5. Saidahmed MT (1990) A novel approach on controllability and stabilization of linear systems with general delayed control. In: Proceeding, 28th Midwest symp. circuits and systems, Aug 1990
6. Sunori SK, Juneja P, Chaturvedi M, Bansal A (2018) System identification of cane carrier process of sugar mill. In: IEEE conference ICACCCN, 12–13 October 2018
7. Sunori SK, Juneja PK, Chaturvedi M, Mittal J (2016) Dead time compensation in sugar crystallization process. Advances in intelligent systems and computing (AISC). Springer, pp 375–381
8. Smith OJM (1959) A controller to overcome dead time. ISA J 6(2):28
9. Behzad H, Khorashadizadeh S, Kalat AA (2011) A robust adaptive method to control the crushing mill machine. ICCIA

Publisher's Note